

interaction, an observation that is not surprising for exposed loops. Interestingly, a residue that is known to be involved in the catalytic action of neuraminidase alters its position drastically on complex formation. This structural change could explain the inhibition of neuraminidase activity by NC41 Fab, which does not directly block the catalytic site. Crystallographic work

on other antigen-antibody complexes is under way, which may help to answer some of the questions raised by Colman *et al.* □

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Organic ferromagnets

Polymers from the Soviet Union

Richard Friend

THE possibility of constructing a ferromagnetic array of spins on radicals in an organic material has been known for some time^{1,2}. Small polyradical molecules have been found that do show strong ferromagnetic exchange coupling between the electron spins within the molecule³. It has not until now been possible either to arrange ferromagnetic coupling between such molecules or to extend them, for example as polymer chains. However, recent work by Ovchinnikov and colleagues in the Soviet Union, reported on page 370 of this issue⁴, shows that a polymer based on polydiacetylene, with nitroxyl biradical side groups, behaves as a ferromagnet, with a Curie temperature of about 150 °C.

The exchange interaction between two spatially localized magnetic spins is usually antiferromagnetic. There are only a handful of examples of non-metallic ferromagnetic salts, in contrast to the thousands of known antiferromagnetic transition metal salts. The reason for this is that the antiferromagnetic spin singlet combination of two interacting spins can

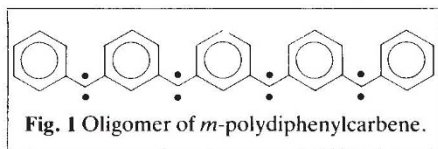


Fig. 1 Oligomer of *m*-polydiphenylcarbene.

occupy a single spatial quantum state, whereas the Pauli principle requires that the ferromagnetic spin triplet occupies higher energy levels. The group of materials where there is scope for building structures with these interactions reversed are organic molecules with extended π electron systems. Many of these molecules have been studied in the past decade for their ability to delocalize charge and behave as metals or high mobility semiconductors. Thus, conjugated polymers such as polyacetylene can show metallic levels of conductivity when doped, as I have recently discussed in a News and Views article⁵, and among the many metallic molecular charge transfer salts there are even some which are superconductors⁶.

The same properties that encourage charge delocalization (extended π mol-

ecular orbitals along a polymer chain, many molecular wavefunctions with similar energies) are also desirable for building materials with interesting magnetic properties. J. Torrance⁷ has developed a straightforward scheme to explain the magnetic interactions between spins in

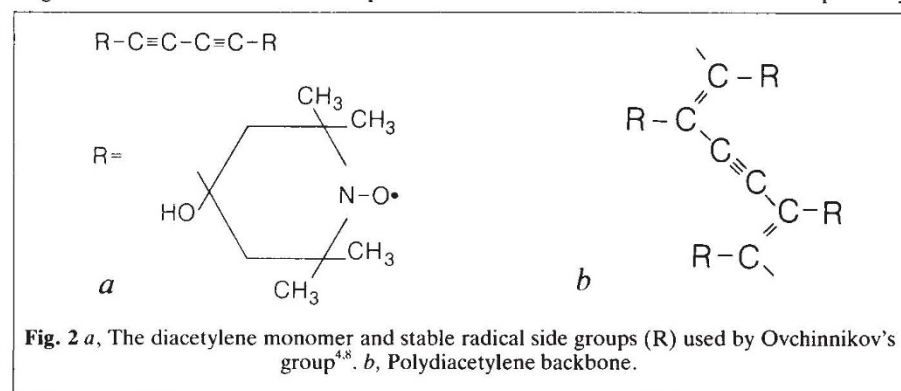


Fig. 2 a, The diacetylene monomer and stable radical side groups (R) used by Ovchinnikov's group^{4,8}. b, Polydiacetylene backbone.

these systems and has shown how it is possible to arrange them to be ferromagnetic. The overlap of wavefunctions on adjacent sites can be considered to mix into the ground-state wavefunction the excited state obtained by transferring the electron spin from one site to the other. If the lowest excited level is non-degenerate it must necessarily be the antiferromagnetic singlet. But if it is degenerate, Hund's rules give the triplet to be lower in energy and ferromagnetic ordering is preferred. These conditions should be met for polymers with π electrons along the chains which are odd-alternate, and very detailed experimental work by Iwamura and co-workers³ has been done on model oligomeric systems of this type. The oligomer of *m*-polydiphenylcarbene shown in Fig. 1, for example, has a total of 8 spins (p_z and non-bonding electron at each bridge site), which are ferromagnetically coupled to give a ninefold degenerate (nonet) ground state. Unfortunately, the larger oligomers have not yet been made, and the coupling between adjacent oligomer molecules in the solid is antiferromagnetic. The way forward is to extend the chains as polymers. Torrance has seen ferromagnetic behaviour in the reacted product of 1,3,5-triaminobenzene and

iodine a few times, and he conjectures that this compound is a partially oxidized *meta*-linked phenyl polymer.

Ovchinnikov and co-workers^{4,8} have followed a different route, and have attached stable radicals as side groups to the diacetylene monomer shown in Fig. 2a. They then polymerized the monomer with heat or exposure to ultraviolet radiation to give a polydiacetylene backbone, shown in Fig. 2b. Whereas the spins on the radicals on the monomer show Curie-like behaviour, those present in the polymer are ferromagnetically coupled. Ovchinnikov and colleagues consider that the exchange interaction in the polymer is mediated by the π electrons along the polymer chain. At present only a small fraction (0.1 per cent) of the monomer is converted to ferromagnetic polymer, although this fraction can be magnetically separated from the residue and shows a respectably

high Curie temperature of 150 °C or above.

These new results are far from ideal, with a poor reaction yield for the synthesis and a poorly characterized product, but they will certainly stimulate further efforts to synthesize other organic ferromagnets. The discovery of ferromagnetism now completes the list for organic materials of those electronic properties (metallic conduction, superconductivity and ferromagnetism) formerly associated only with inorganic materials. It will be some time to come, however, before organic ferromagnets find applications in place of traditional magnetic materials. □

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